

Direct Model Reference Adaptive Internal Model Controller for DFIG Wind Farms

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Abstract—This paper presents the Direct model reference adaptive internal model controller for doubly fed induction generator used in wind farms based on MIT Rule adjustment mechanism. Direct model reference adaptive internal model controller is developed and it is tuned using MIT rule. Rotor current controller is designed using direct model reference adaptive internal model controller to improve the robust performance of the system. The performance is compared with conventional internal model controller and it is described. Flexibility of proposed method in shunt connection is illustrated, dynamic response under fault causes sag condition, like sudden drop in terminal voltage changing affected the behavior of the machine, this phenomenon is simulated using MATLAB/SIMULINK and it is presented.

Index Terms—Model reference, Adaptive internal model Controller, MIT Rule, DFIG, wind farms.

NOMENCLATURE

V_s = stator voltage [V]
 R_s = stator resistance [Ω]
 i_s = stator current [A]
 σ = leakage coefficient
 ω_e = synchronous frequency [rad/s]
 λ_s = stator flux [wbturns]
 V_r = rotor voltage [V]
 R_r = rotor resistance [Ω]
 i_r = rotor current [A]
 ω_r = rotor speed [rad/s]
 λ_r = rotor flux [wbturns]
 V_{ds} = stator direct axis voltage [V]
 i_{ds} = stator direct axis current [A]
 λ_{ds} = stator direct axis flux [wbturns]
 V_{qs} = stator quadrature axis voltage [V]
 i_{qs} = stator quadrature axis current [A]
 λ_{qs} = stator quadrature axis flux [wbturns]
 V_{dr} = rotor direct axis voltage [V]
 i_{dr} = rotor direct axis current [A]

λ_{dr} = rotor direct axis flux [wbturns]
 V_{qr} = rotor quadrature axis voltage [V]
 i_{qr} = rotor quadrature axis current [A]
 λ_{qr} = rotor quadrature axis flux [wbturns]
 L_r = leakage inductance [H]
 L_m = magnetizing inductance [H]
 i_{ms} = stator magnetizing current [A]
 C = capacitance [F]
 J = inertia of the rotor [kg-m^2]
 D = active damping torque
 $P = \frac{d}{dt}$ (derivative function).

I. INTRODUCTION

Rapid industrialization and application of technology in the agricultural sector has prompted the demand for power. Conservation of conventional fossil fuels such as coal, oil etc is the main advantage of renewable energy sources. Recent news says that in china pollution from factories and power plants was increasing by 9% a year. One-third of China's vast landmass is suffering from acid rain caused by its rapid industrial growth.

DFIG is the best suited variable speed wind generator for high power wind farms apart from complex control tragedy. Immense research work is in process on the DFIG throughout the world

The important key issues concerning wind farms are economic grid connections. Grid integration point is used to determine the prices in wind farms. The integration of wind power in the power system is, therefore, now an issue to optimize the utilization of the resources and to achieve the goals of sustainability and security of supply. According to present requirements, wind turbines should remain connected and actively support the grid during faults. This requirement became essential because the contribution of power generated by a wind farm can be significant and it was at risk of being lost as in the past practices. Earlier, wind turbines were simply disconnected from the grid during faulty condition and reconnected when the fault is cleared and the voltage returned to normal.

Internal Model Controller (IMC) is robust controller, proposed in 1982. Paper [1] presented parameter nonlinearity and dynamic response of the DFIG with less significant improvements. John Morren et al [2] paper clearly explained about fault ride through, and used IMC controller to overcome this phenomenon. Adaptive

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controller is implemented in DFIG [3] without IMC and model reference approach. Direct model reference adaptive IMC with improved filter design is presented in [4].

In this paper, direct model reference adaptive IMC, DFIG control for wind farms to improve the performance during fault sag conditions. To the best of authors' knowledge, this approach is made possible first time applied to DFIG control. The proposed method is very general and there are different versions possible. The effectiveness of the proposed approach is tested on a practical wind farm system.

II. MODELLING OF DFIG

Fig.1 shows the general block diagram of grid connected DFIG wind farm and back-to-back converter and its controller. DFIG is the suitable Generator for high power windmill applications because of its high efficiency; high power handling capacity, and the rotor and stator is also separated from grid. The main disadvantage of using DFIG is losses due to power electronics circuits. Advance technologies with power quality monitoring and SVC can meet these challenges.

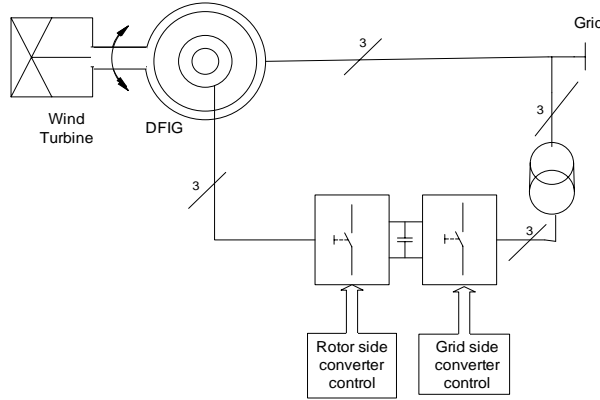


Fig.1. General DFIG wind turbine

A. Mathematical Model of the DFIG

The well-known d-q axis theory model of the DFIG described is in [5]. To simplify the theory, first order system with L_d, i_d, i_q, ω_e variations have been considered and given below.

$$V_s = -R_s i_s + \sigma \frac{d\lambda_s}{dt} - j\omega_e \lambda_s \quad (1)$$

$$V_r = -R_r i_r + \sigma \frac{d\lambda_r}{dt} - j(\omega_e - \omega_r) \lambda_r \quad (2)$$

$$\text{In stationary reference frame} \quad \omega_e = 0 \quad (3)$$

By applying d-q theory Equation (3) becomes

$$V_{ds} = -R_s i_{ds} + \sigma \frac{d\lambda_{ds}}{dt} \quad (4)$$

$$V_{qs} = -R_s i_{qs} + \sigma \frac{d\lambda_{qs}}{dt} \quad (5)$$

In addition, (4) becomes

$$V_{dr} = -R_r i_{dr} + \sigma \frac{d\lambda_{dr}}{dt} + j\omega_r \lambda_{dr} \quad (6)$$

$$V_{qr} = -R_r i_{qr} + \sigma \frac{d\lambda_{qr}}{dt} - j\omega_r \lambda_{qr} \quad (7)$$

Flux linkage equations

$$\lambda_{dr} = (L_r + L_m) i_{dr} + L_m i_{ds} \quad (8)$$

$$\lambda_{qr} = (L_r + L_m) i_{qr} + L_m i_{qs} \quad (9)$$

$$\lambda_{ds} = (L_s + L_m) i_{ds} + L_m i_{dr} \quad (10)$$

$$\lambda_{qs} = (L_s + L_m) i_{qs} + L_m i_{qr} \quad (11)$$

$$\lambda_{ds} = L_m i_{ms} \quad (12)$$

By rearranging these equations $V_{ds}, V_{qs}, V_{dr}, V_{qr}$ becomes,

$$P\lambda_{ds} = f(V_{ds}, V_{qs}, V_{dr}, V_{qr}) \quad (13)$$

$$P\lambda_{qs} = f(V_{ds}, V_{qs}, V_{dr}, V_{qr}) \quad (14)$$

$$P\lambda_{dr} = f(V_{ds}, V_{qs}, V_{dr}, V_{qr}) \quad (15)$$

$$P\lambda_{qr} = f(V_{ds}, V_{qs}, V_{dr}, V_{qr}) \quad (16)$$

Simulink model is developed using these equations [6] [7].

III. CONTROLLER DESIGN

Rotor current control is mostly employed in DFIG wind farms because it is efficient to improve the performance during fault [8].

A. Internal Model Controller

Fig.2. shows the general IMC approach. Internal model principle is implemented and explained in [9]. The IMC design takes in account the model uncertainties and it allows straight forward relation of controller settings with the model parameters. In first order system, IMC controller, which is insensitive to time delay and parameter deviation, is roughly equal to the PI controller for first order system [10]. The response of IMC is sluggish although it does not have any overshoot [11] and integral action of this controller is used to eliminate offset. The closed loop transfer function of IMC is

$$Y(s) = \frac{G_{imc}(s)G_p(s)R(s) + [1 - G_{imc}(s)G_{inv}(s)]d(s)}{1 + [G_p(s) - G_{inv}(s)]G_{imc}(s)} \quad (17)$$

B. controller Design

The IMC controller design method is prescribed in [12] for first order system.

$$\text{First order Plant model } G_p = \frac{K}{1 + \tau s} \quad (18)$$

$$\text{Internal model } G_{inv} = \frac{1 + \tau s}{K} \quad (19)$$

Low pass filter F is used to avoid model mismatch

$$F = \frac{1}{(1 + \phi s)^n} \quad (20)$$

ϕ =speed response tuning parameter, n =order of low pass filter (used to add right number of poles to compensate zeros), For first order system normally $n=1$,

$$H = FG_{inv} = \frac{1+\tau s}{K(1+\phi s)^n} \quad (21)$$

The controller is

$$G_c = \frac{H}{1-HG_{inv}} = \frac{1+\tau s}{K\phi s} \quad (22)$$

IMC is stable in low frequencies because of the low pass filter used in the controller.

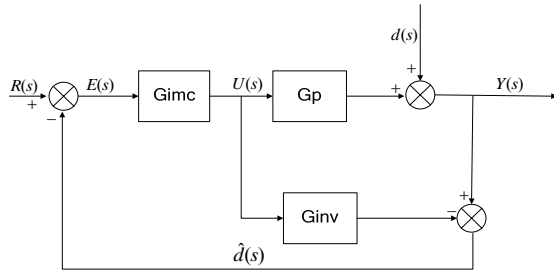


Fig. 2. General IMC diagram

C. Adaptive Internal Model Controller

Fig 3 shows the general adaptive internal model control diagram. Adaptive internal model controller is a non-linear controller, which is used to change the model and controller according to the change in the plant parameters. The IMC controller do not consider the time delay but AIMC considers the changes of parameters due to time delay in the plant. The deign procedure of AIMC are in explained [13]. This controller is also called as frequency domain adaptive internal model controller.

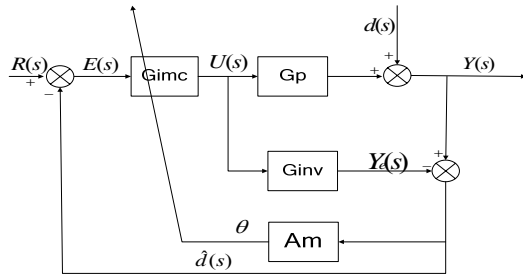


Fig. 3 General adaptive IMC diagram

D. Direct model Reference Adaptive IMC using MIT Rule

Fig. 4 shows the general direct model reference adaptive internal model controller diagram. Whitaker and his co-workers [14] first suggested model reference adaptive controller. Internal model controller is highly depended on model accuracy but model reference adaptations with internal model controller even handle partially known systems and it's self-tuning controller.

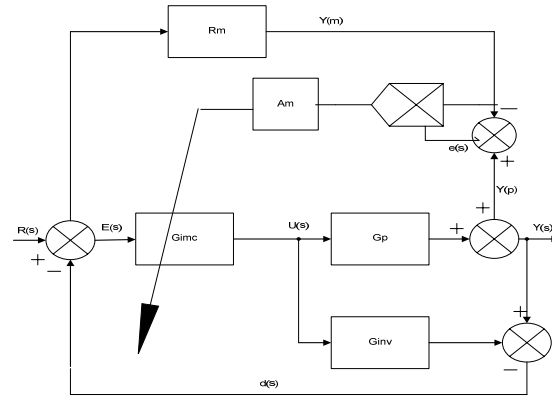


Fig. 4. General direct model reference adaptive IMC diagram using MIT rule

a) Reference model

The reference model of this controller is based on [15]. A first order reference model is considered for first order plant. Reference model is used to increase the sensitivity of the process and to reduce the model uncertainty.

$$\text{Reference model } R_m = \frac{KZ}{\rho} \quad (23)$$

Where, K is reference gain, Z is the reference zeros and ρ is reference poles.

b) Adjustment Mechanism using MIT Rule

The famous Lyapunov theory based adaptation law may not work well in practice [16]. MIT Rule is otherwise called sensitivity approach, and straightforward gradient approach. MIT Rule based adjustment mechanism will not give stable closed loop system, which is the main disadvantage of this system.

$$e(S) = y(S) - y_m(S) \geq 0, \text{ is driven to zero} \quad (24)$$

$$\text{Cost function } \theta = -\eta \frac{\delta e}{\delta \theta} \quad (25)$$

Where θ is adjustable parameter vector, η is the tuning rate to determine the convergence speed and $\delta e / \delta \theta$ is the sensitivity derivative.

MIT rule based adjustment mechanism (Am)

$$\theta = -\frac{\gamma}{s} e(s) y_m(S) \quad \gamma > 0 \quad (26)$$

Where γ =adaptation gain (smaller value will give better result), High gain in adjustment mechanism causes instability of the system and also affects its performance.

E. Rotor side control

The shaft and gear are connected at one end of the rotor and is used to produce a torque to do the useful work. According to energy conservation principle, the mechanical power absorbed is equal to electrical power produced by back emf, neglecting losses of the system. The d- and q-axis rotor currents are controlled separately using this transfer function which is derived from (8)-(13).

IV. SIMULATION RESULTS

The proposed controller is tested on a system as shown in Fig. 5. A wind farm consisting of six 1.5-MW DFIG wind turbines is connected to a 25-kV distribution system exports power to a 120-kV grid through a 25-km, 25-kV cable. The parameters of DFIG are given in appendix.

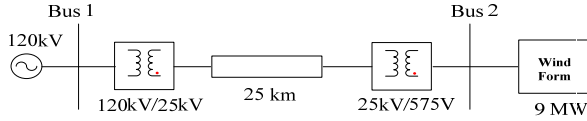


Fig.5.Schematic diagram of simulated system

Simulation using SIMULINK is compactable in both control system and power system point of view. A dip of 50% is applied at the terminal of DFIG to see the dynamic performance of the controllers, which can be seen from Fig.6.

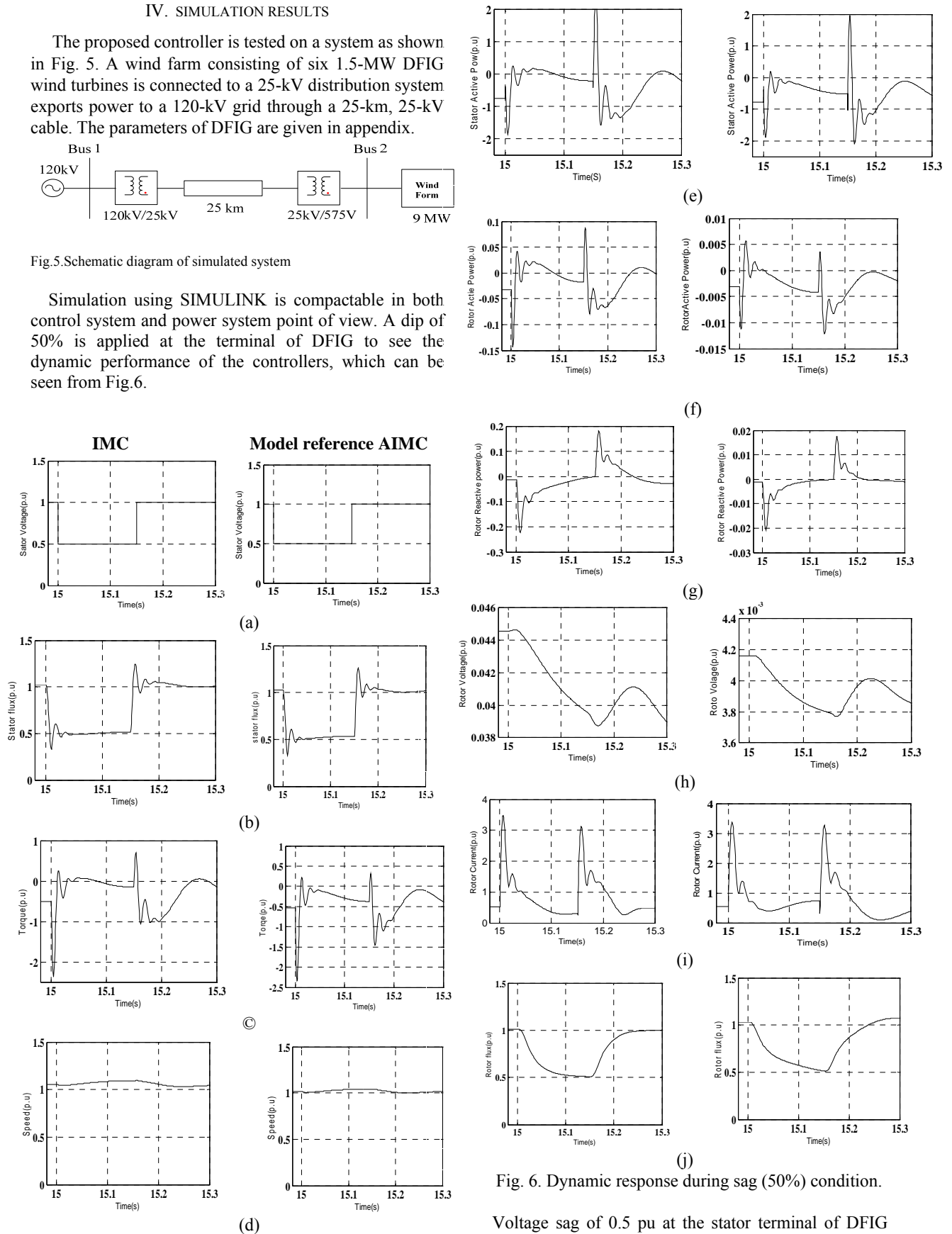


Fig. 6. Dynamic response during sag (50%) condition.

Voltage sag of 0.5 pu at the stator terminal of DFIG has been considered during 15.0 s to 15.50 s as shown in

Fig. 6. It is seen that the response is improved and its oscillations are well damped. DC dynamics are significantly reduced. The peak over-shoots of the stator current and rotor current are reduced and show the safe and reliable DFIG operation.

V. CONCLUSION

Improvements in model reference adaptive Internal Model Controller is shown and is well suited for practical application. The comparison between conventional IMC and the DMRAIMC is made using SIMULINK. The dynamic performance of DFIG is improved significantly using this controller. From this simulation, the active and reactive power compensation is better using direct model reference adaptive controller.

APPENDIX A

TABLE I.
PARAMETERS OF SIMULATED DFIG

Rated Power	1.5 MW
Stator Voltage	575V
R_s	0.0071 (p.u.)
R_r	0.005 (p.u.) (referred to stator)
L_s	0.171 p.u.
L_r	0.156 (p.u.) (referred to stator)
L_m	2.9 (p.u.)
Number of Pole Pairs	3
J	0.5 (p.u.)
D	0.01 (p.u.)
σ	0.1761 (p.u.)
Base wind speed	12 m/s

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BIOGRAPHIES



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